MEMS Gas Sensors

Dr. Abdul Rehman Abbasi

SMOG ALERT
IN LAHORE!
ہوا کی کوالٹی بدترین سطح پر

What the difference between fog and smog?

Smog

- It is pollution.
- Waste gases and smoke from cars, homes, and factories.

Fog

- It is condensation.
- It is created by warm water moist air moving over cold water.

Air Quality Index		
AQI Category and Color	**Index Value**	**Description of Air Quality**
Good Green	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Moderate Yellow	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups Orange	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Unhealthy Red	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy Purple	201 to 300	Health alert: The risk of health effects is increased for everyone.
Hazardous Maroon	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

India Air Quality Forecast for 18Nov2024 Monday

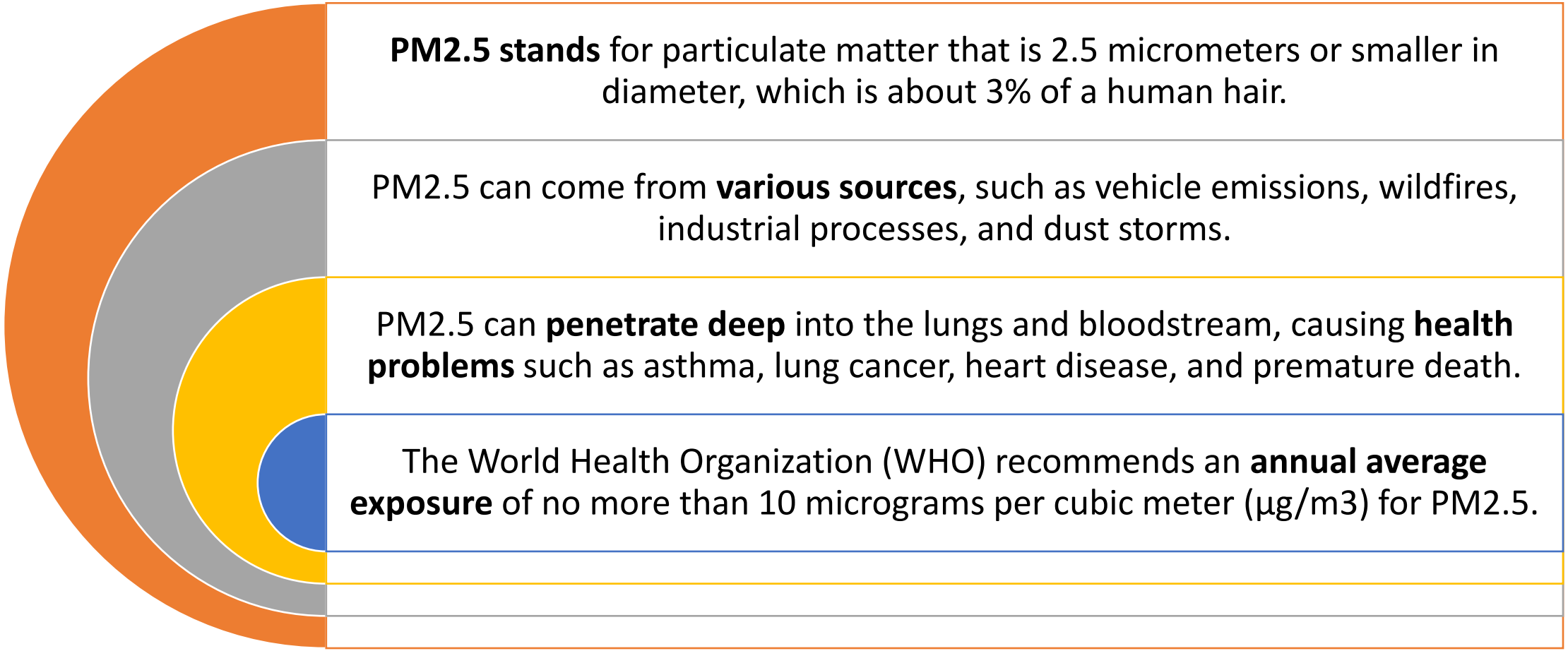
Air Quality Index (AQI) for PM2.5

no. of districts by AQI bin

States/UTs	All districts						
Andaman & Nicobar	3	3	-	-	-	-	-
Andhra Pradesh	13	-	13	-	-	-	-
Arunachal Pradesh	16	16	-	-	-	-	-
Assam	27	27	-	-	-	-	-
Bihar	38	-	4	20	12	2	-
Chandigarh	1	-	1	-	-	-	-
Chhattisgarh	18	-	14	4	-	-	-
Dadra & Nagar Haveli	1	-	1	-	-	-	-
Daman & Diu	2	-	2	-	-	-	-
Delhi	9	-	-	-	1	8	-
Goa	2	-	2	-	-	-	-
Gujarat	26	-	22	3	1	-	-
Haryana	21	-	14	4	2	1	-
Himachal Pradesh	12	11	1	-	-	-	-
Jammu & Kashmir	22	14	8	-	-	-	-
Jharkhand	24	-	6	18	-	-	-
Karnataka	30	3	27	-	-	-	-
Kerala	14	13	1	-	-	-	-
Lakshadweep	1	1	-	-	-	-	-
Madhya Pradesh	50	-	33	17	-	-	-
Maharashtra	35	-	30	5	-	-	-
Manipur	9	9	-	-	-	-	-
Meghalaya	7	7	-	-	-	-	-
Mizoram	8	8	-	-	-	-	-
Nagaland	11	11	-	-	-	-	-
Odisha	30	-	12	18	-	-	-
Puducherry	4	3	1	-	-	-	-
Punjab	20	1	17	2	-	-	-
Rajasthan	33	1	21	11	-	-	-
Sikkim	4	4	-	-	-	-	-
Tamilnadu	32	15	17	-	-	-	-
Telangana	10	-	6	3	1	-	-
Trupura	4	3	1	-	-	-	-
Uttar Pradesh	71	-	18	43	10	-	-
Uttarakhand	13	12	1	-	-	-	-
West Bengal	19	2	4	9	3	1	-
India	**640**	164	277	157	30	12	-

URBAN emissions .info

PM2.5



PM2.5 stands for particulate matter that is 2.5 micrometers or smaller in diameter, which is about 3% of a human hair.

PM2.5 can come from **various sources**, such as vehicle emissions, wildfires, industrial processes, and dust storms.

PM2.5 can **penetrate deep** into the lungs and bloodstream, causing **health problems** such as asthma, lung cancer, heart disease, and premature death.

The World Health Organization (WHO) recommends an **annual average exposure** of no more than 10 micrograms per cubic meter (µg/m3) for PM2.5.

Remedy for PM2.5

To **reduce exposure** to PM2.5, people can check the **air quality index** (AQI), avoid **outdoor activities** when the levels are high, use **air filters** or purifiers at home, and **wear masks** when necessary

Volatile Organic Compounds (VOCs)

are organic chemicals that have a high vapor pressure at room temperature. They are often found in solvents, paints, varnishes, and other products, and can have negative effects on air quality and human health.

What is the relevancy?

- Effective methods to monitor toxic gases and VOCs are in demand for atmospheric environmental measurements and control, as well as human well-being and health monitoring.

What is the relevancy?

- highly sensitive analytical techniques such as gas chromatography (GC), spectrophotometry, and high-performance liquid chromatography (HPLC), have been used for accurate quantification of these gases.
- What are the Pain Points?

cost, lack of portability, and high-power demand,

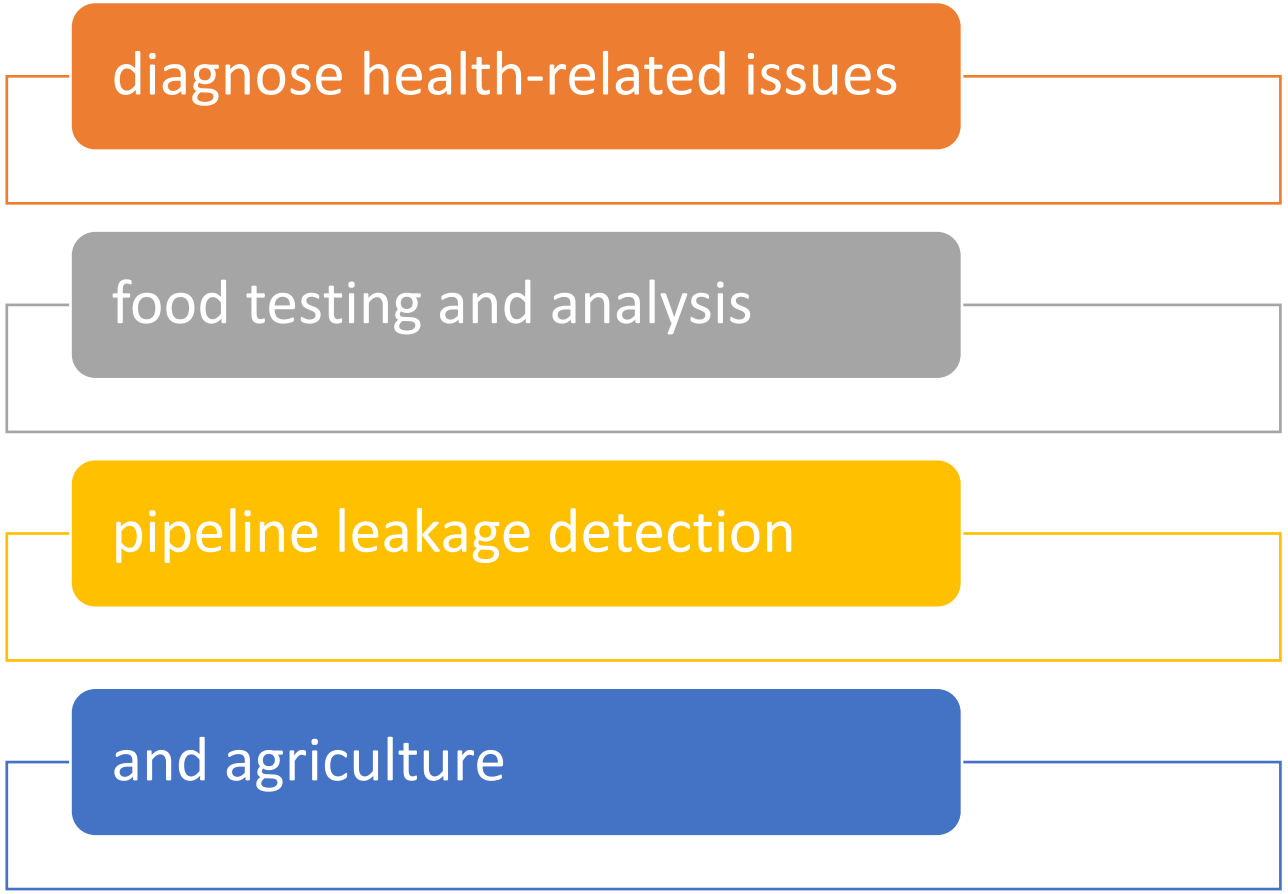
the use of such techniques often requires complex and time-consuming pre-treatment steps, and highly skilled operators.

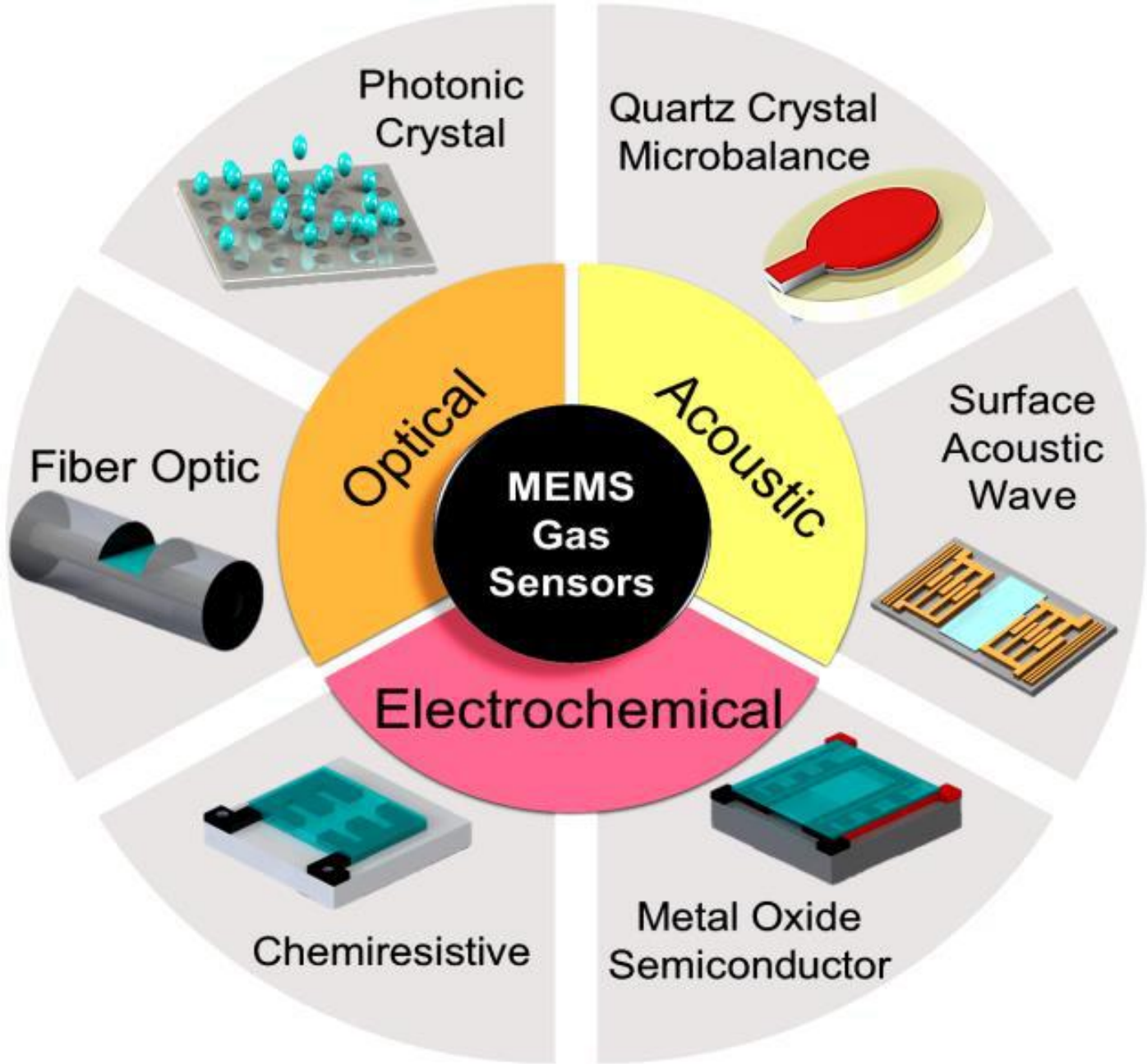
MEMS Gas Sensing

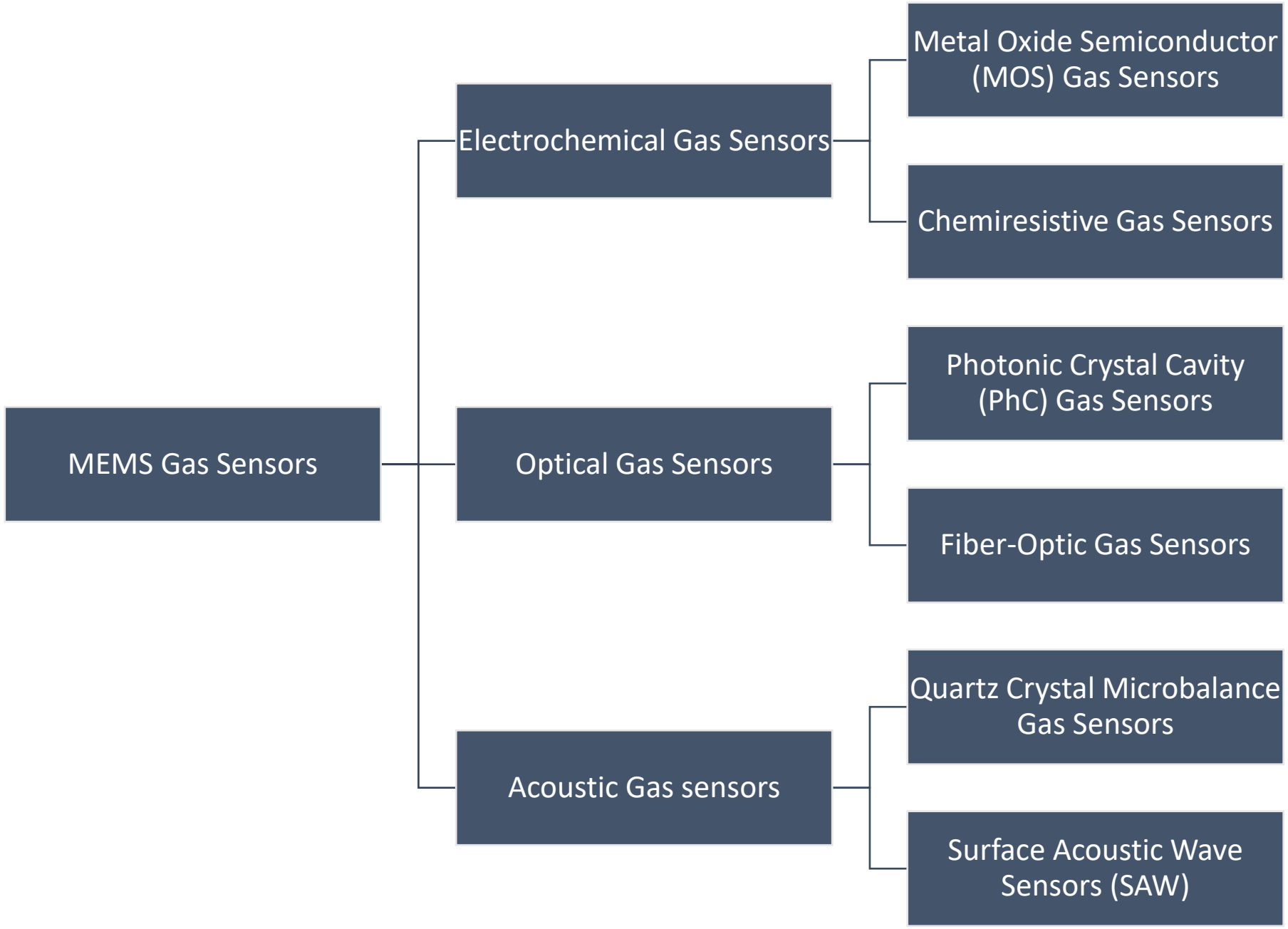
Micro-electromechanical system (MEMS) gas sensors represent a system that is capable of detecting the existence and concentration of gasses in the atmosphere

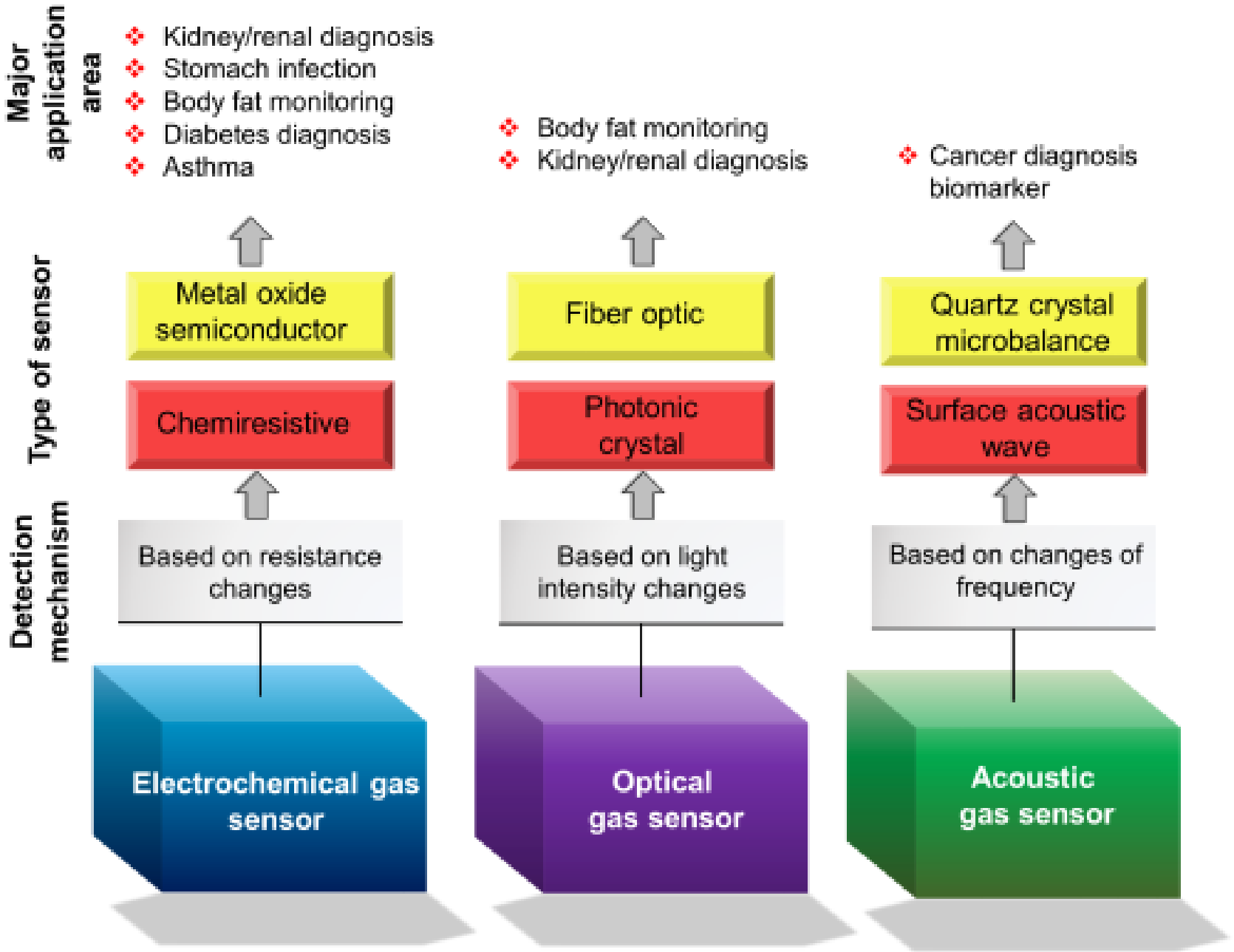
The MEMS gas sensing mechanisms such as electrochemical, optical, and acoustics, are developed because of advantageous features such as higher sensitivity, lower power consumption, smaller designs, and a much lower fabrication cost, compared to the traditional gas sensors

MEMS based gas sensors are use for monitoring pollutant gases but also used in other applications



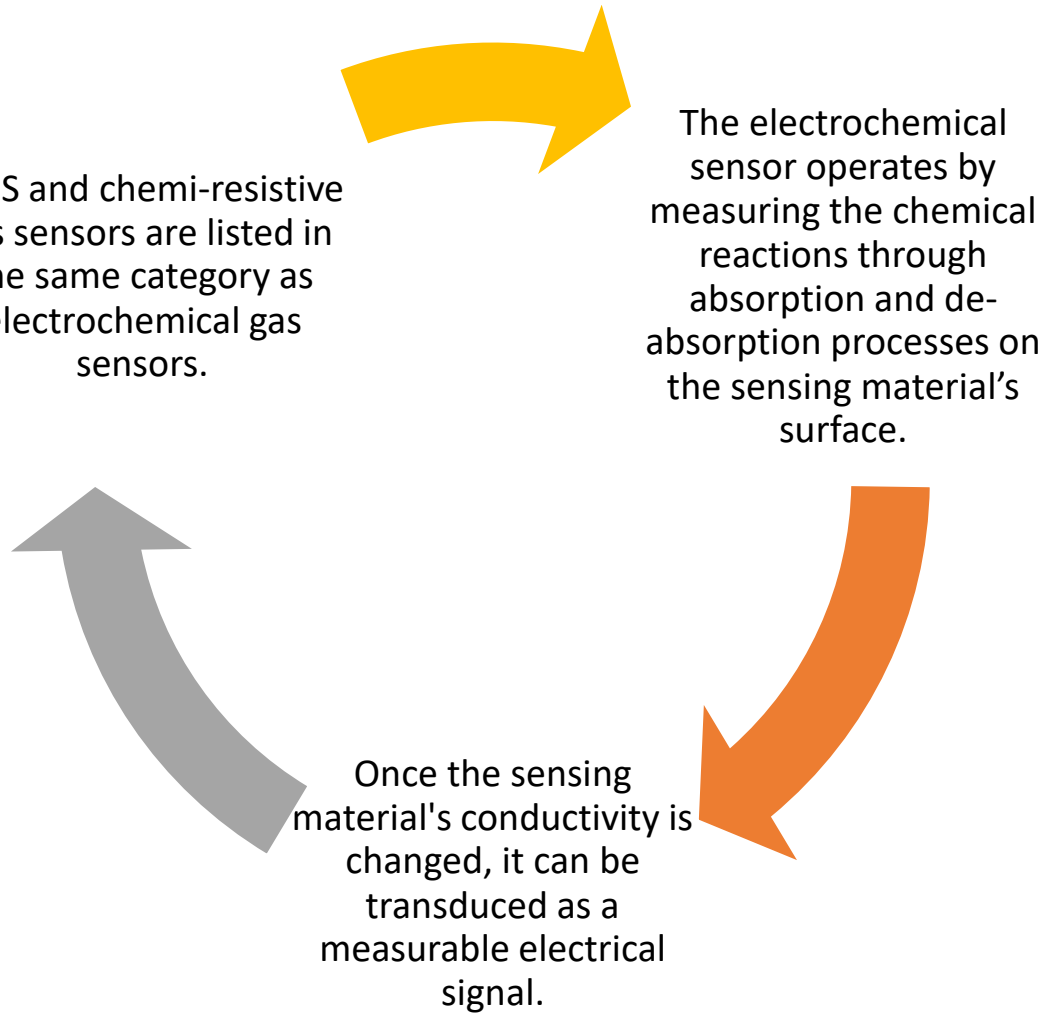

Photonic Crystal
Quartz Crystal Microbalance
Fiber Optic
Optical
Acoustic
MEMS Gas Sensors
Surface Acoustic Wave
Electrochemical
Chemiresistive
Metal Oxide Semiconductor


MEMS Gas Sensors
Electrochemical Gas Sensors
Metal Oxide Semiconductor (MOS) Gas Sensors
Chemiresistive Gas Sensors
Optical Gas Sensors
Photonic Crystal Cavity (PhC) Gas Sensors
Fiber-Optic Gas Sensors
Acoustic Gas sensors
Quartz Crystal Microbalance Gas Sensors
Surface Acoustic Wave Sensors (SAW)

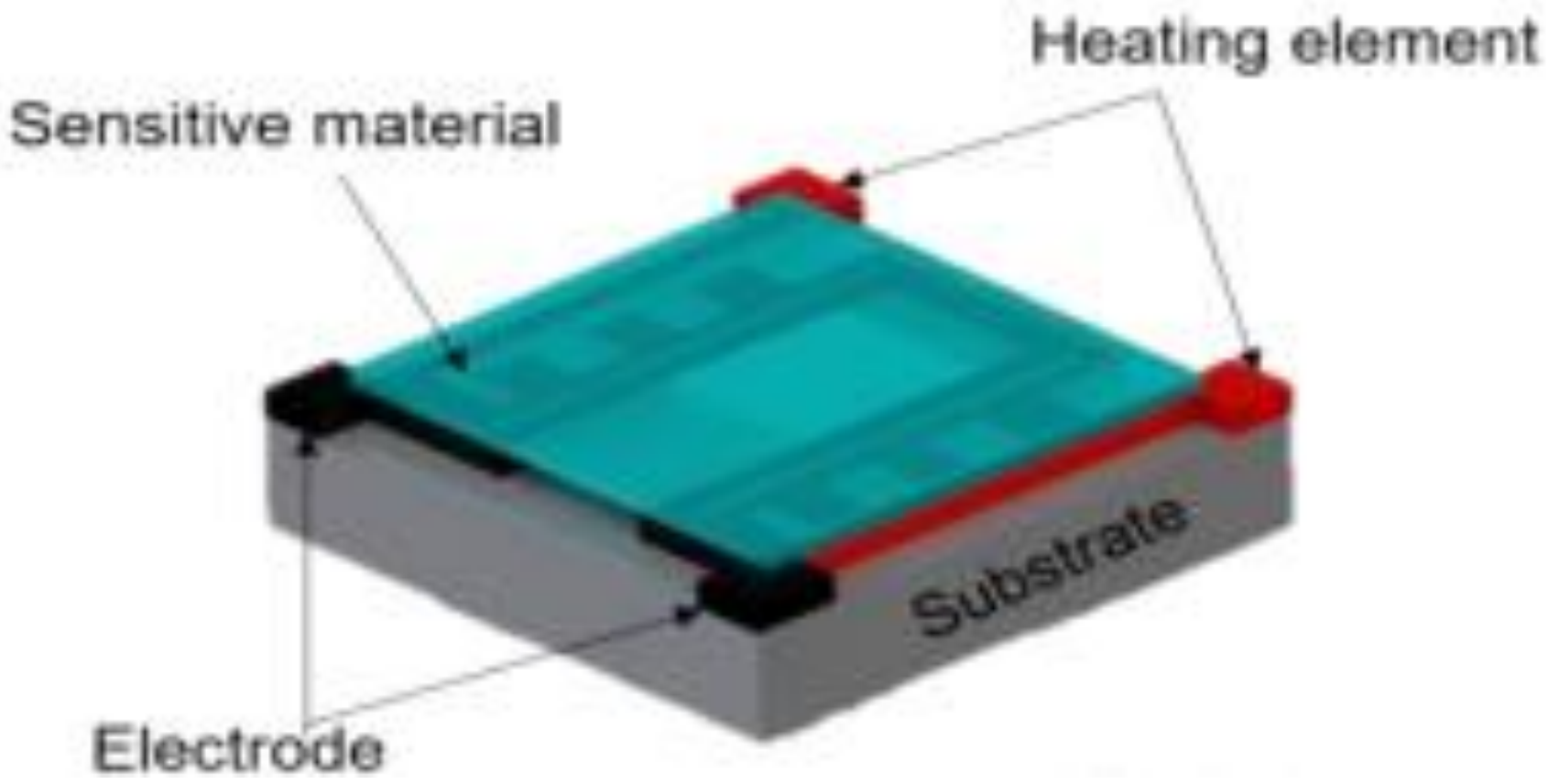


MEMS GAS SENSOR

Q1: How does the Electrochemical Gas Sensor work?


The electrochemical sensor operates by measuring the chemical reactions through absorption and de-absorption processes on the sensing material’s surface.
Once the sensing material's conductivity is changed, it can be transduced as a measurable electrical signal.
MOS and chemi-resistive gas sensors are listed in the same category as electrochemical gas sensors.

Q2: Draw the Schematic Diagram of MOS Gas Sensor?



Q3 Explain the mechanism?

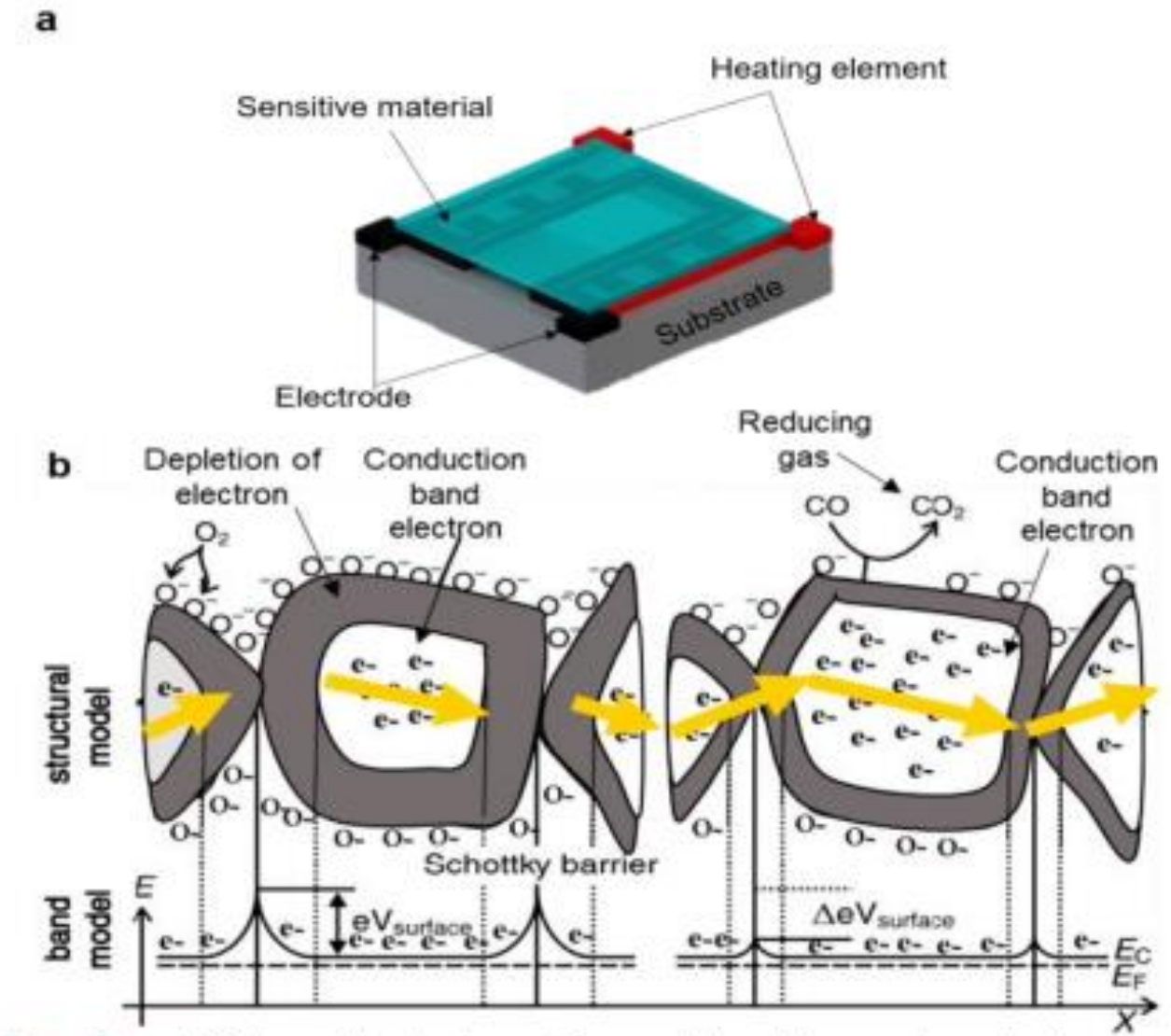
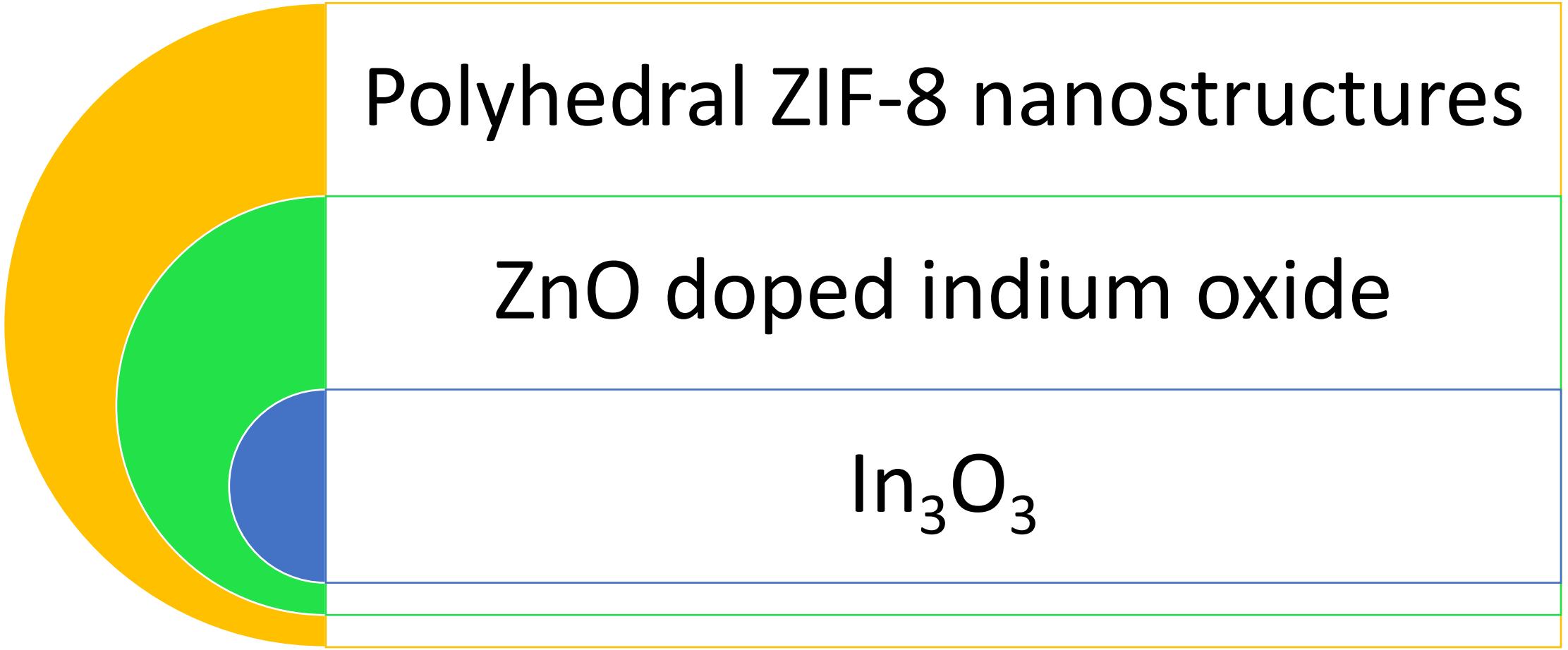


Fig. 2. (a) Schematic design of a metal oxide semiconductor gas sensor. (b) Mechanism of *n*-type MOS gas sensor in double Schottky barrier model.

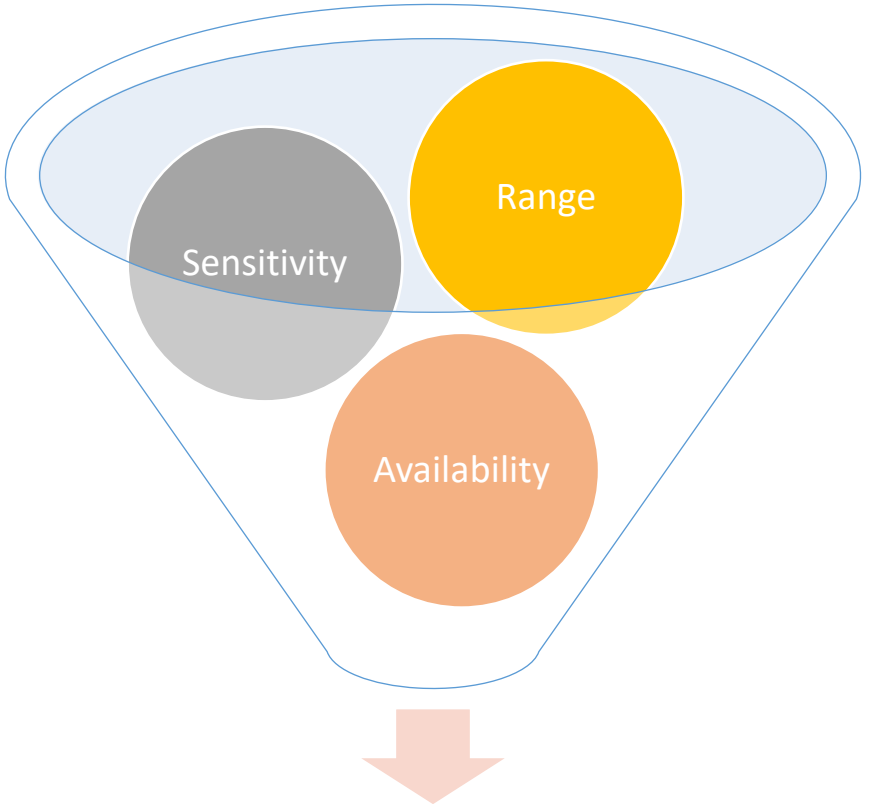
Q4: Name atleast three sensitive materials for NO_2 Gas Sensing?



Which method has the highest resolution?

In_3O_3 (In PPB)

Q5: How to improve the performance of the MOS gas sensor ?

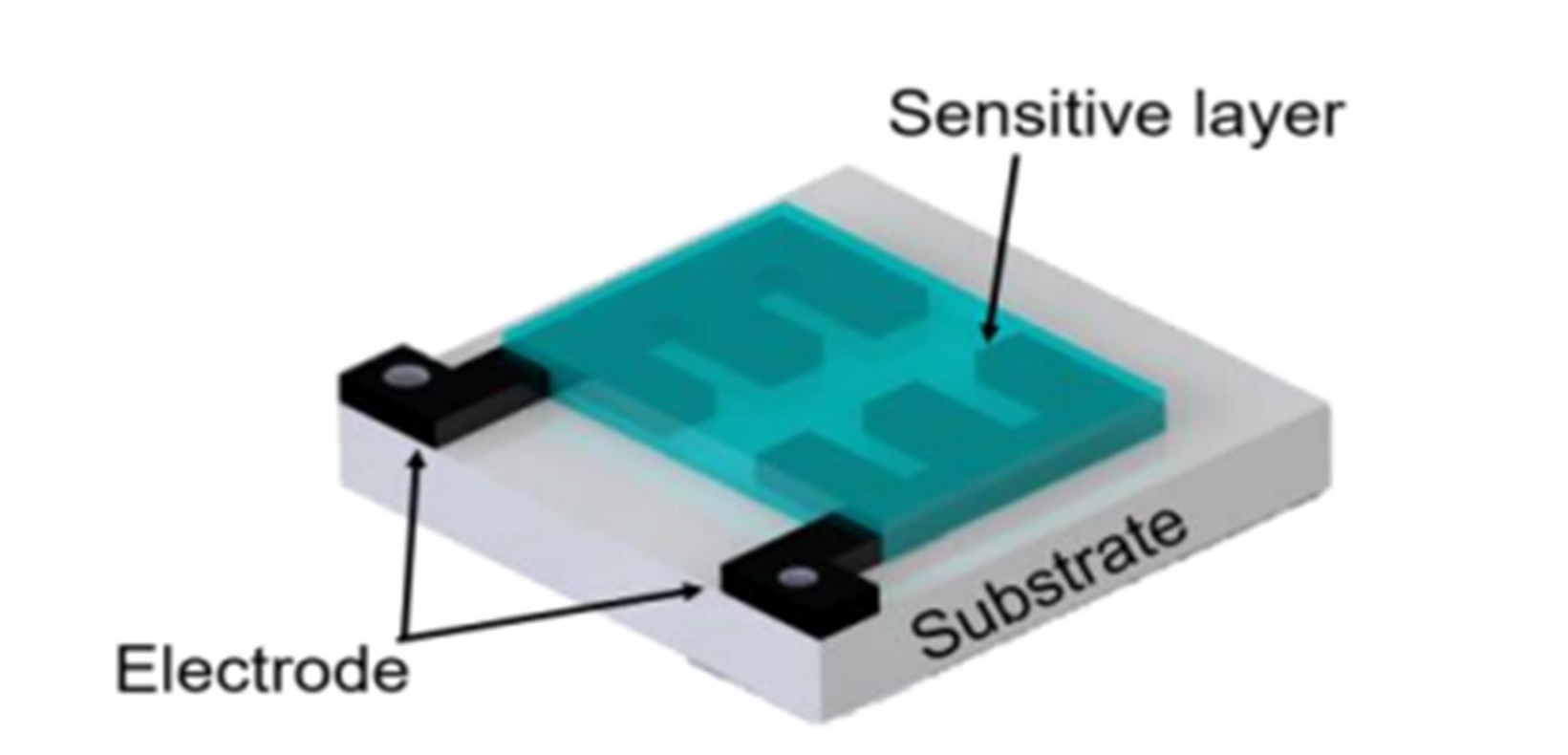


Choice of Material is the key

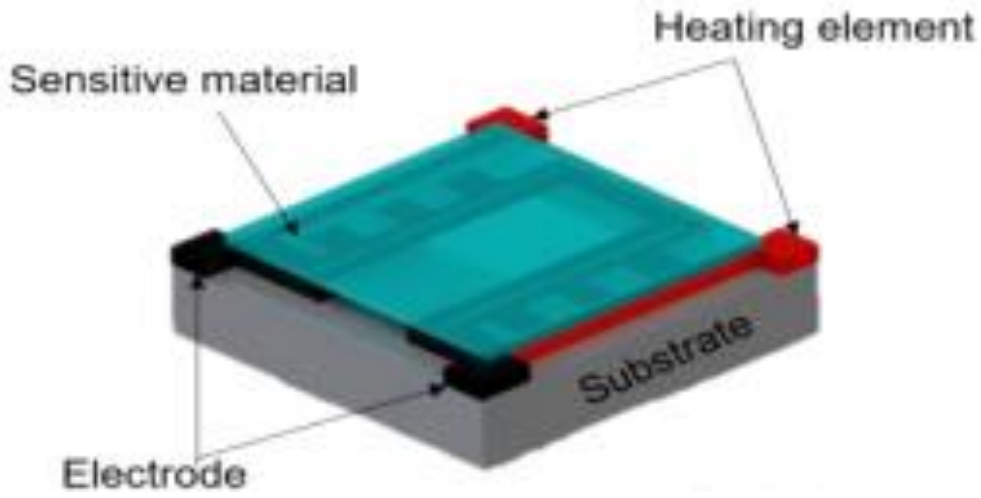
Q6: Which material is the most sensitive and stable for MEMS based gas sensors?

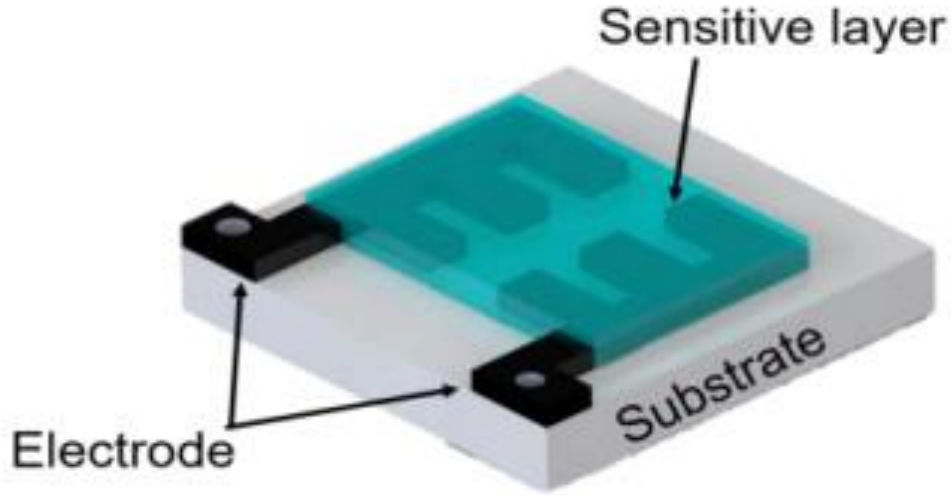
SnO_2

Q7: Draw schematic diagram of chemi-resistive gas sensor.



Q8: Differentiate in MOS and Chemi-resistive gas sensor.





Q9: How does chemi-resistive gas sensor work?

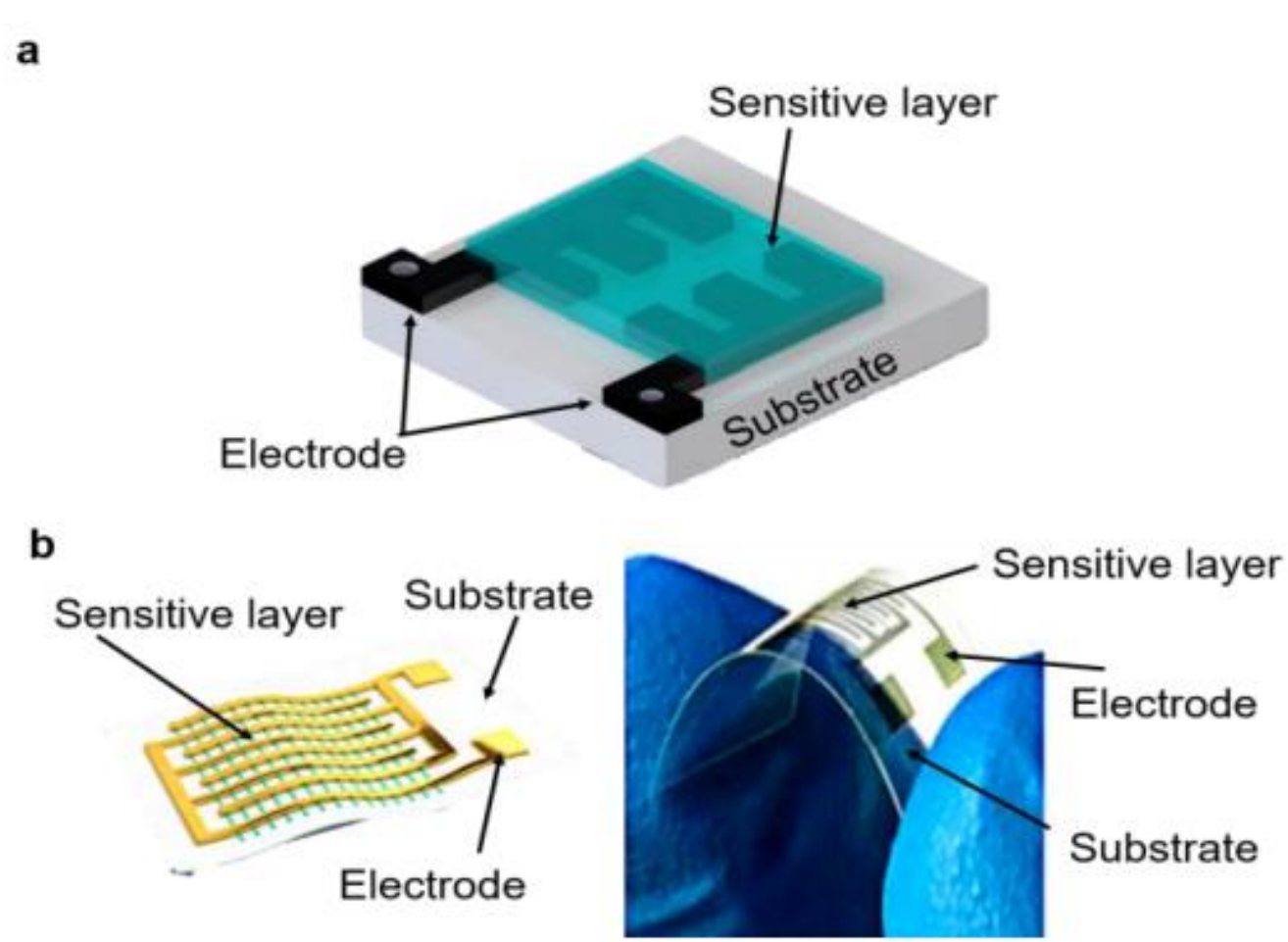


Fig. 3. (a) Schematic design of a chemiresistive gas sensor. (b) Flexible chemiresistive gas sensor. Reprinted from [100], Copyright (2019), with American Chemical Society.

Q10: How does QCM gas senso work?

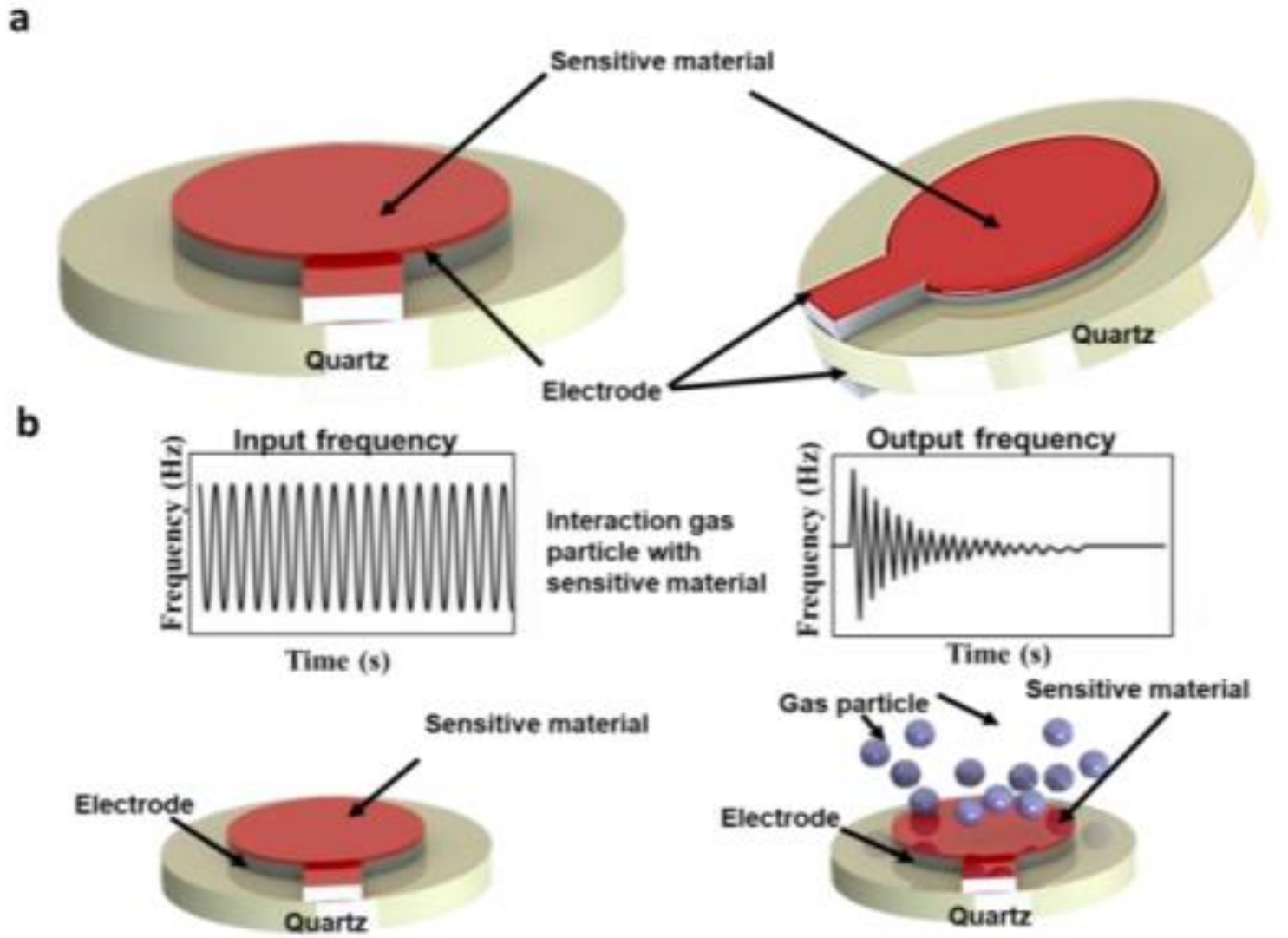


Fig. 6. (a) Schematic design and (b) Working mechanism of a QCM sensor gas sensor.

Q11: How does SAW gas sensor work?

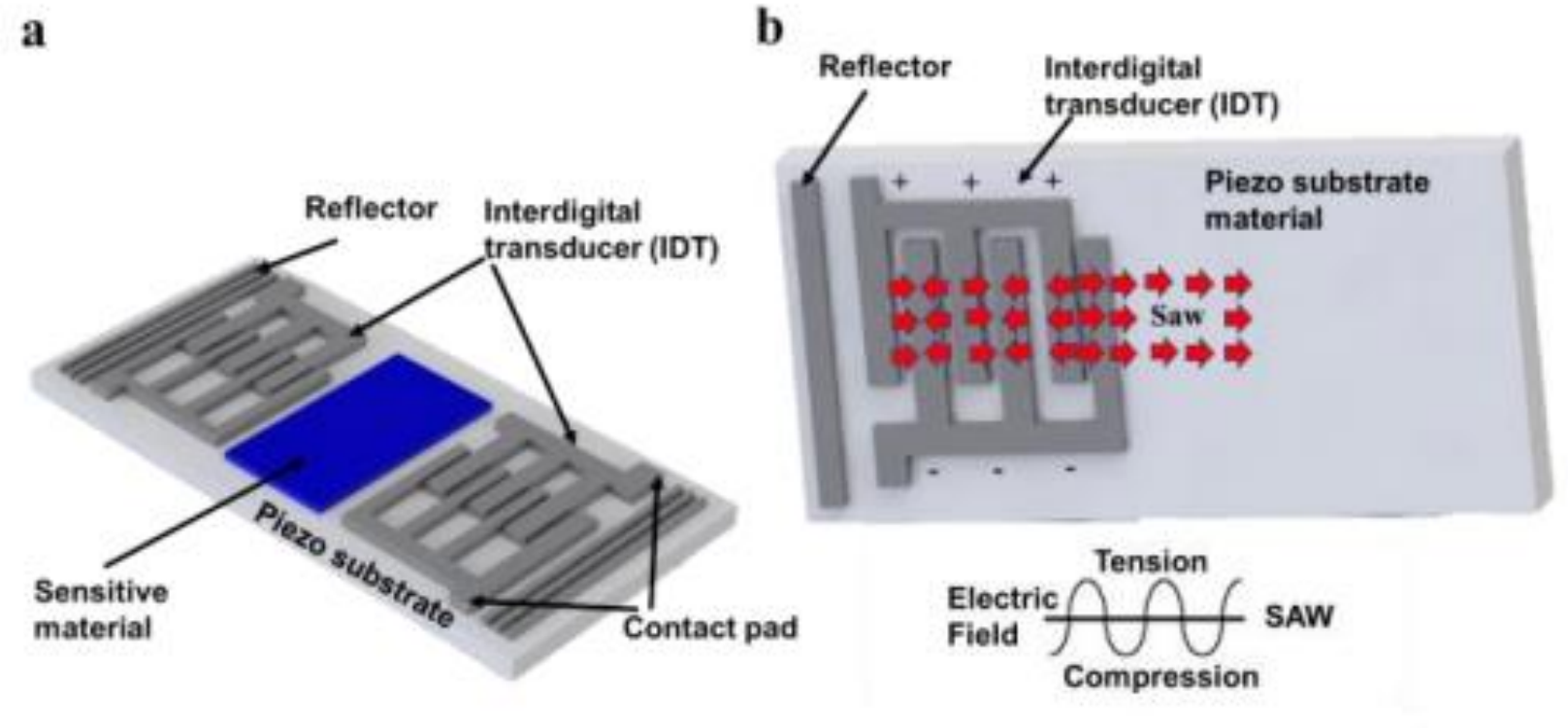


Fig. 7. (a) Schematic diagram and (b) Working mechanism of a SAW gas sensor.

Q12: How does PhC gas sensor work?

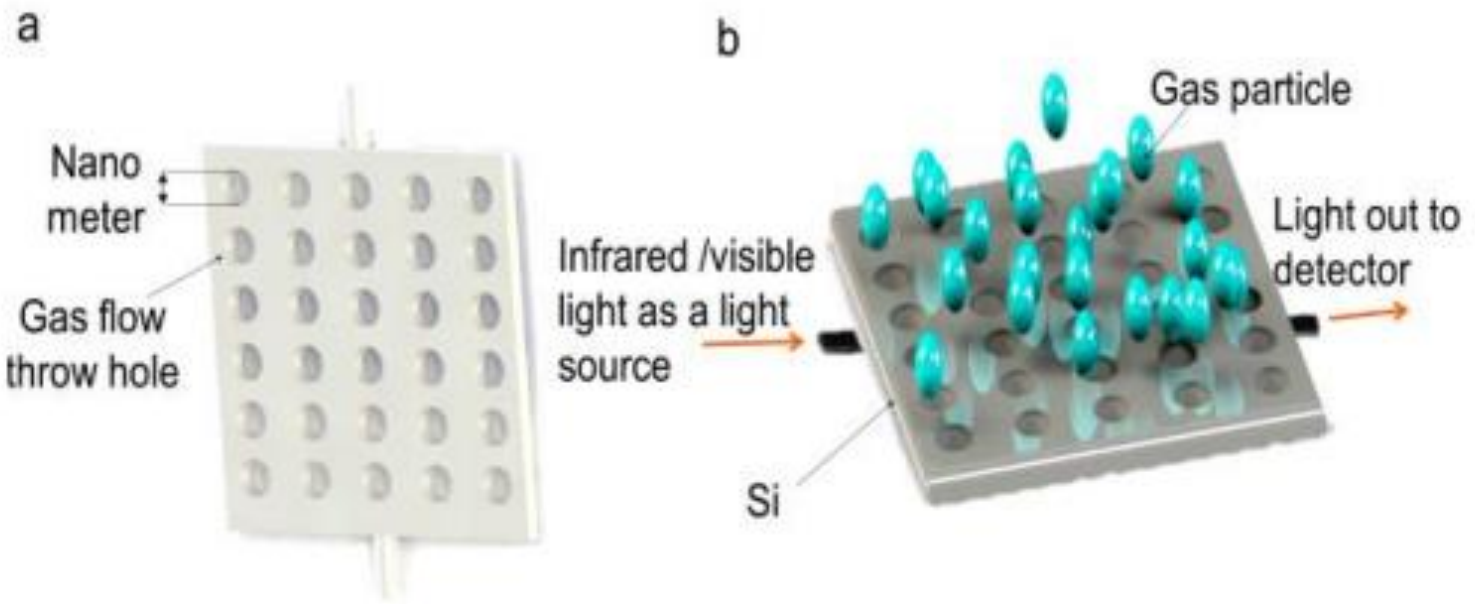
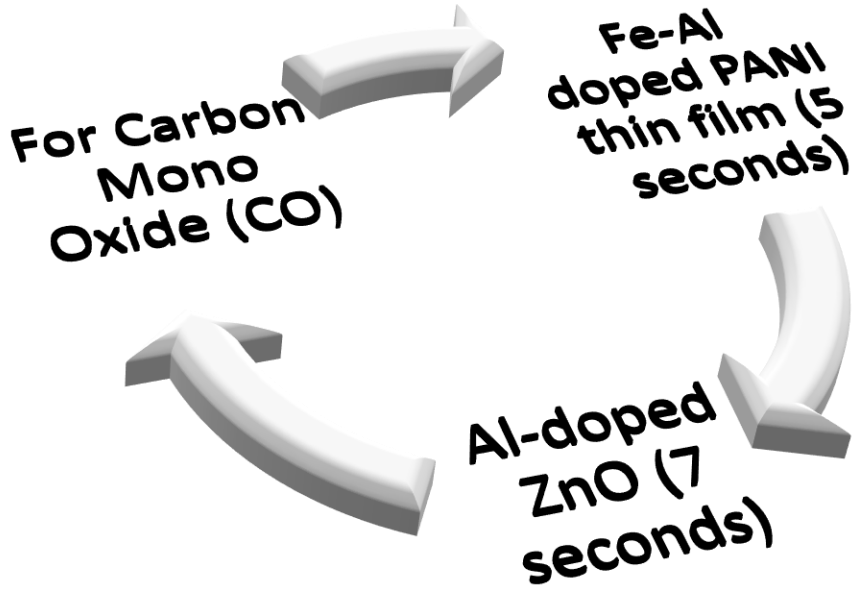


Fig. 4. (a) Schematic view of a photonic crystal gas sensor. (b) Mechanism of a PhC gas sensor.

Q13: Which Chemiresistive gas sensor provides the quickest response and for which gas?



Q14: Fill in the blanks

Gas	Material Type	Category Type	Sensitivity/Resolution/ Range
CO			
CH_4			
NO_X			
NH_3			

Q15: Which method is useful for VOC and thus to check on health hazards due to SMOG crisis?

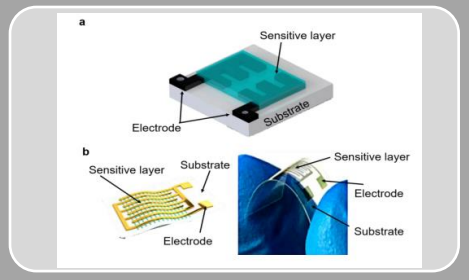
- Explore……..

Table VII

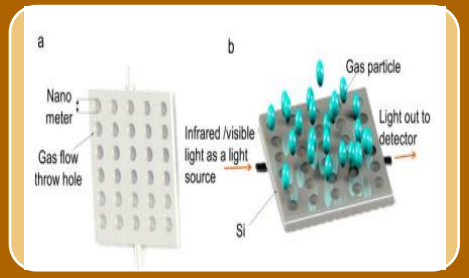
SUMMARY AND PERFORMANCE COMPARISON OF THE MEMS GAS SENSORS

Major MEMS Gas Sensors	Working Principle	Advantages	Limitations	Applications
Electrochemical	Based on changes of resistance	Low cost [30, 33], short response time and recovery time [30], wide range of target gases [4, 118], and high sensitivity at high temperature [4].	The sensitivity of the sensitive material is reduced time by time because heat, low sensitivity and selectivity [118, 158], sensitive to environmental factors [32], and high power consumption [118, 4, 158].	Biomedical: Diabetic diagnosis [174, 177], stomach infection diagnosis [8], and Kidney disease diagnosis [24,34]. Gas: CO [42-44, 55, 71], H_2 [29, 38, 41, 70], NO_2 [30, 33, 39, 50, 72, 73], C_5H_6OH [32, 35, 36, 38], NH_3 [14, 40, 62, 65], C_3H_6O [63], CH_3O_3 [46], CH_2O[49, 69], and C_5H_8 [31].
Optical gas sensor	Based on changes of light intensity	Long lifetime [3, 118], high selectivity and stability [118], higher sensitivity [109-111], insensitive to environmental change [4], operate in a wide range [4] and not easily affected by electromagnetic interference.	High cost [118], difficulty in miniaturization the design because of limitations due to the size of an external light source and photodetector [4,118], and easily affected by ambient light interference [118].	Biomedical: Fat burn monitoring [182] and kidney disease diagnosis [172]. Gas: H_2 [85, 109-111], NH_3 [103, 104, 107], CH_3OH [107, 112,114-116], CO_2 [89, 106], No_2 [108], C_3H_6O [112], CH_4 [82], H_2S [81, 83], C_6H_{14} [87], THF vapor [86], acetylene [85], and C_2H_5OH [101, 112].
Acoustic gas sensor	Based changes of frequency	High sensitivity [159], short response [4], fast response, long lifetime [4], low power consumption [4, 23], could be placed in harsh and rotating parts [4], small design [134, 138], and long-term stability.	Easily effected by temperature and humidity [118, 4] and difficult in handling during the fabrication process [4].	Biomedical: Lung cancer biomarker [179, 180]. Gas: HC [157], CO_2 [159, 63], CO [134, 141-143], NO_2 [145, 148, 169-171], NH_3 [132, 133, 138-140, 149, 164-168], and H_2 [158, 160-163].

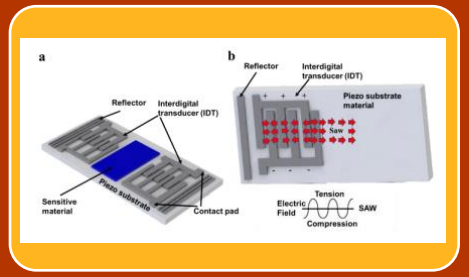
Takeaways



Electrochemical gas sensors work based on the changes in the resistance of sensitive materials. Different types of electrochemical gas sensors, such as MOS and chemi-resistive gas sensors are utilized for diabetic and stomach infection diagnosis, as well as monitoring of the industrial gases.

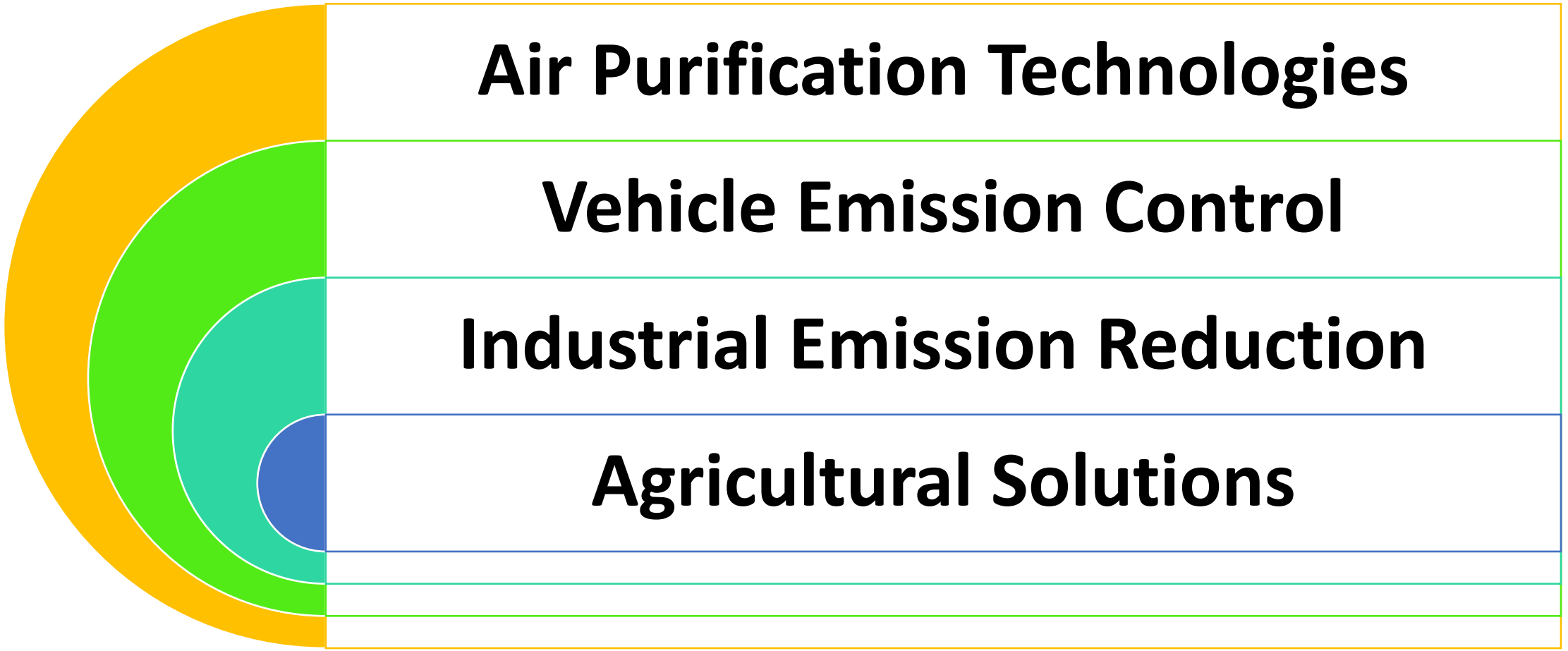


The changes in the light reflection of the optical MEMS gas sensor have been applied for biomedical diagnosis and monitoring devices, such as diabetic diagnostics, and fat burn monitoring, respectively.



Lastly, with much higher sensitivity and stability for acoustic MEMS gas sensors have been developed as lung cancer biomarker devices, and for industry monitoring of toxic gases such CO2, CO, and NH3.

Technical Solutions for SMOG Remedy/Control

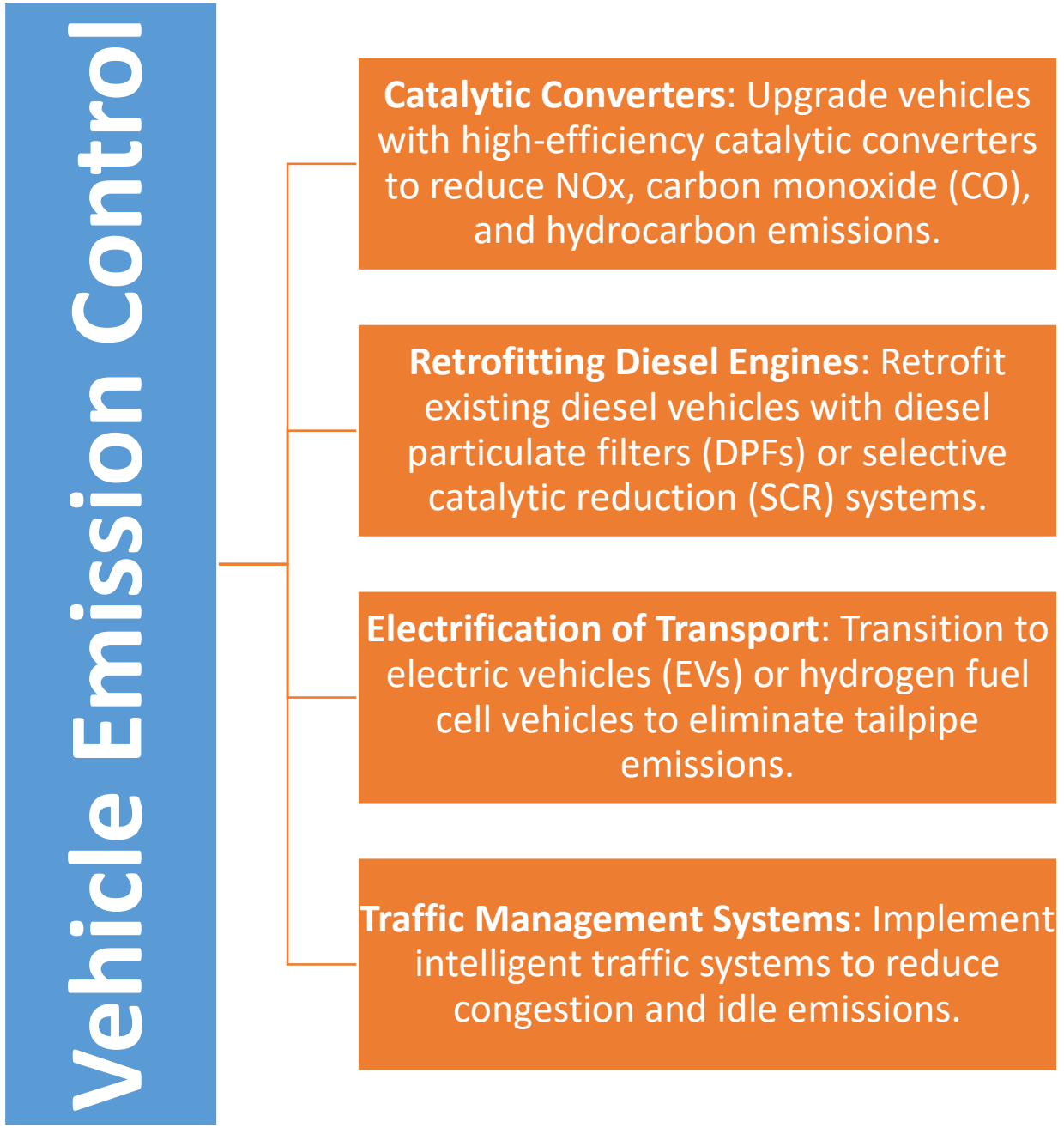


Air Purification Technologies

Large-Scale Air Purifiers: Install outdoor air purifiers (e.g., smog towers) in urban areas to filter out particulate matter (PM2.5 and PM10) and other pollutants.

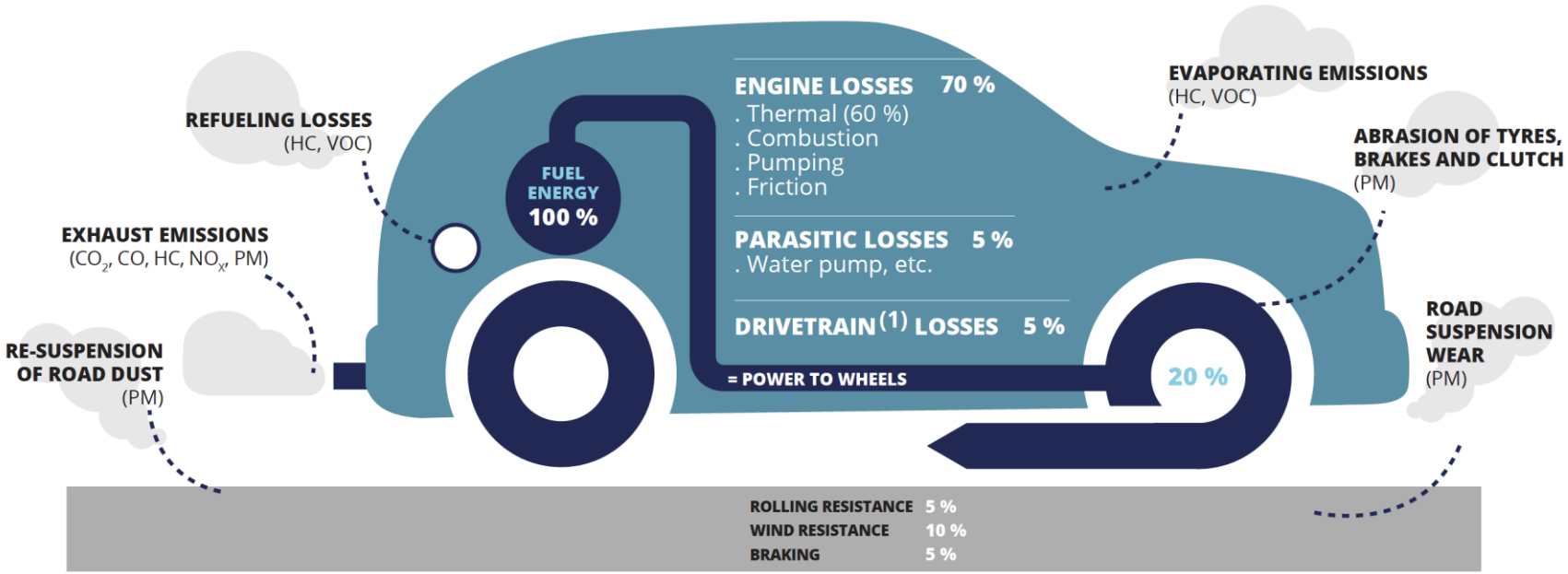
Ionization Technology: Use ionization-based systems to remove fine particulates from the air.

Photocatalytic Oxidation: Employ systems that break down harmful pollutants like nitrogen oxides (NOx) and volatile organic compounds (VOCs) using UV light and catalysts.


Vehicle Emission Control
Catalytic Converters: Upgrade vehicles with high-efficiency catalytic converters to reduce NOx, carbon monoxide (CO), and hydrocarbon emissions.
Retrofitting Diesel Engines: Retrofit existing diesel vehicles with diesel particulate filters (DPFs) or selective catalytic reduction (SCR) systems.
Electrification of Transport: Transition to electric vehicles (EVs) or hydrogen fuel cell vehicles to eliminate tailpipe emissions.
Traffic Management Systems: Implement intelligent traffic systems to reduce congestion and idle emissions.

Vehicle emissions and efficiency

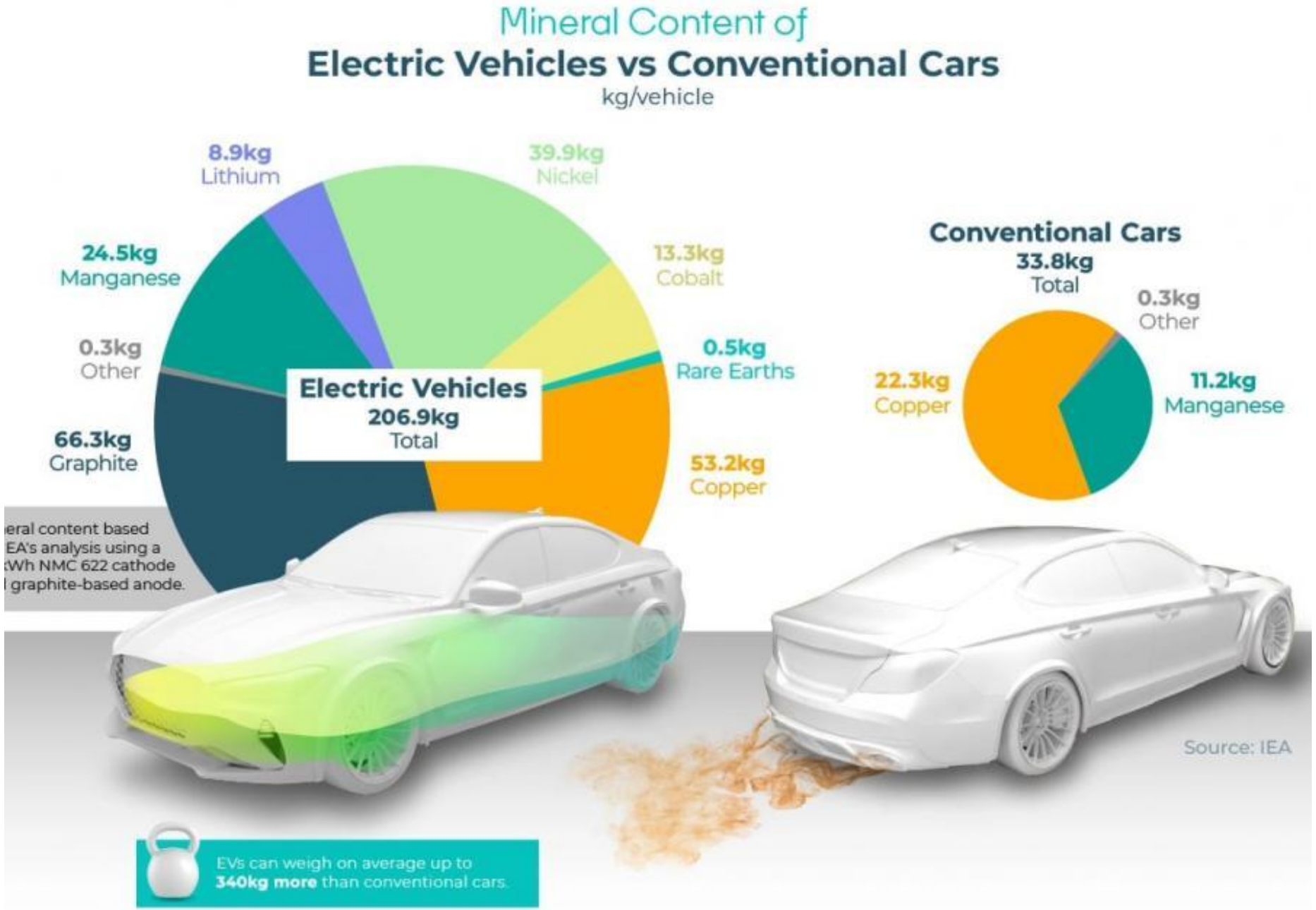
Fossil fuel powered road transport represents the most significant source of transport related air pollution. Each vehicle releases pollutants from a number of sources.

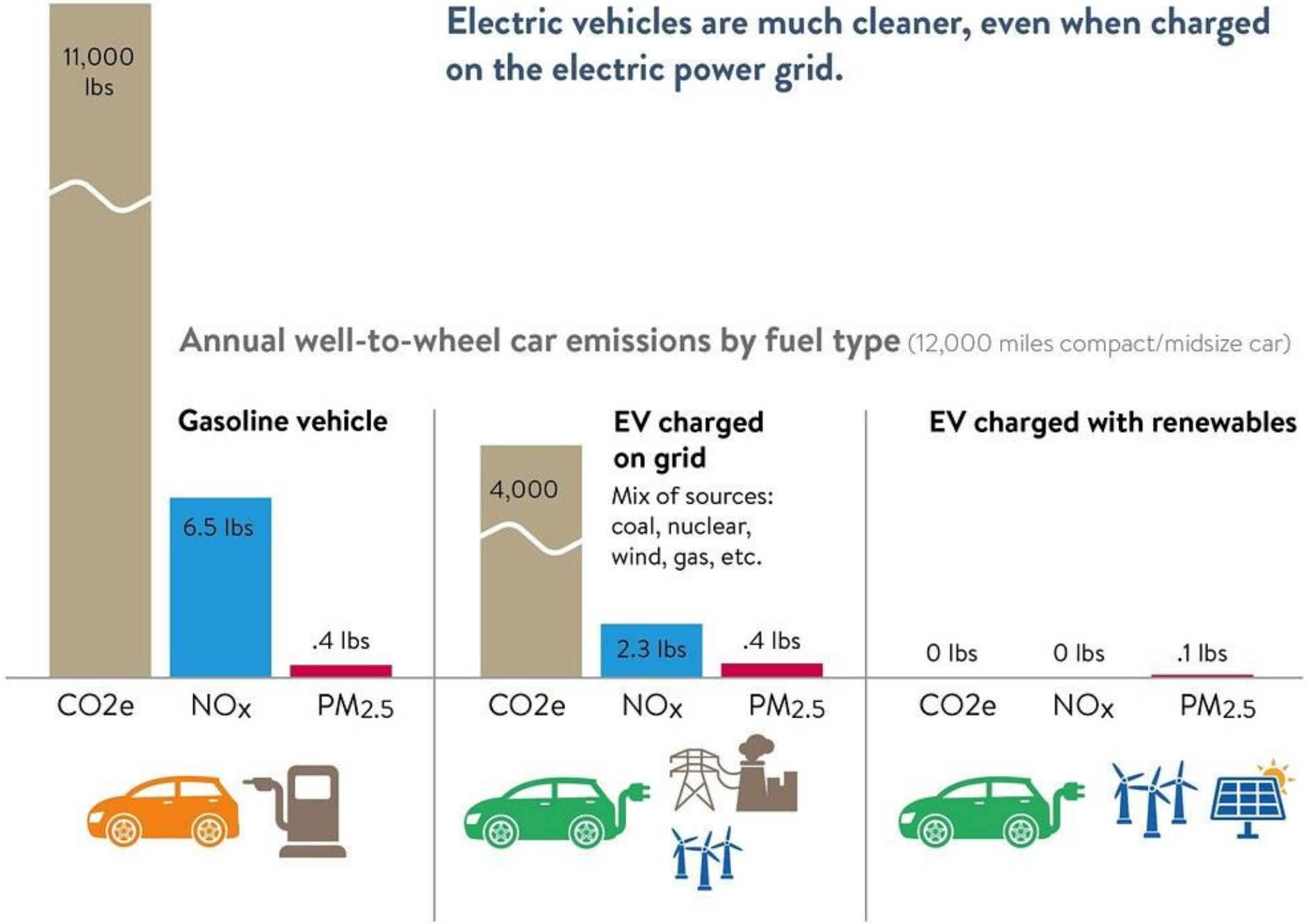


(1) The drivetrain of a motor vehicle is the group of components that deliver power to the driving wheels. This includes the transmission, the axles and the wheels.

HC - Hydrocarbons; **VOC** - Volatile Organic Compound; **PM** - Particulate Matter; **CO** - Carbon monoxide; **CO_2** - Carbon dioxide; **NO_x** - Nittrogen oxides.

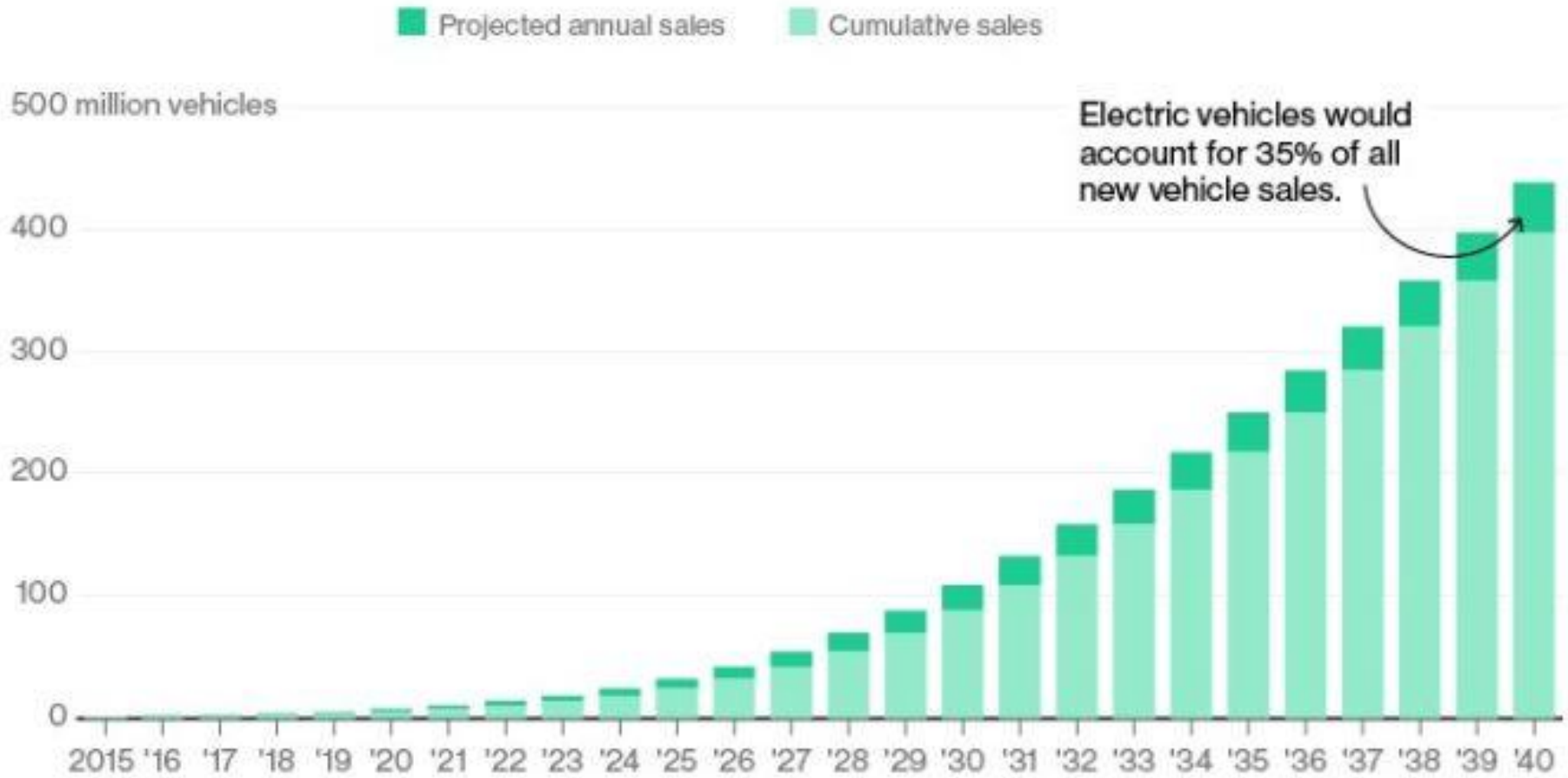
Source: EEA Report — Explaining road transport emissions — a non-technical guide (2016)


Mineral Content of
Electric Vehicles vs Conventional Cars
kg/vehicle
8.9kg
Lithium
39.9kg
Nickel
24.5kg
Manganese
13.3kg
Cobalt
0.3kg
Other
0.5kg
Rare Earths
Electric Vehicles
206.9kg
Total
66.3kg
Graphite
53.2kg
Copper
eral content based
EA's analysis using a
Wh NMC 622 cathode
graphite-based anode.
Conventional Cars
33.8kg
Total
0.3kg
Other
22.3kg
Copper
11.2kg
Manganese
Source: IEA
EVs can weigh on average up to
340kg more than conventional cars.


Electric vehicles are much cleaner, even when charged on the electric power grid.
Annual well-to-wheel car emissions by fuel type (12,000 miles compact/midsize car)
Gasoline vehicle
11,000 lbs
6.5 lbs
.4 lbs
CO2e
NOx
PM2.5
EV charged on grid
Mix of sources: coal, nuclear, wind, gas, etc.
4,000
2.3 lbs
.4 lbs
CO2e
NOx
PM2.5
EV charged with renewables
0 lbs
0 lbs
.1 lbs
CO2e
NOx
PM2.5

The Rise of Electric Cars

By 2022 electric vehicles will cost the same as their internal-combustion counterparts. That's the point of liftoff for sales.


Projected annual sales
Cumulative sales
500 million vehicles
400
300
200
100
0
Electric vehicles would account for 35% of all new vehicle sales.
2015 '16 '17 '18 '19 '20 '21 '22 '23 '24 '25 '26 '27 '28 '29 '30 '31 '32 '33 '34 '35 '36 '37 '38 '39 '40

Sources: Data compiled by Bloomberg New Energy Finance, Marklines

Bloomberg

Industrial Emission Reduction

Electrostatic Precipitators (ESPs): Install ESPs in industrial chimneys to capture particulate matter from flue gases.

Scrubbers: Use wet or dry scrubbers in factories to neutralize SO2, NOx, and other gaseous pollutants.

Low-NOx Burners: Install burners that minimize the formation of nitrogen oxides during combustion.

Happy Seeder Technology: Provide farmers with "Happy Seeders," which allow them to plant crops without burning stubble, reducing emissions significantly.

Biomass Management: Develop technologies to convert crop residue into bioenergy or compost.

Satellite Monitoring: Use satellite-based systems to detect and address stubble burning in real-time.

Agricultural Solutions

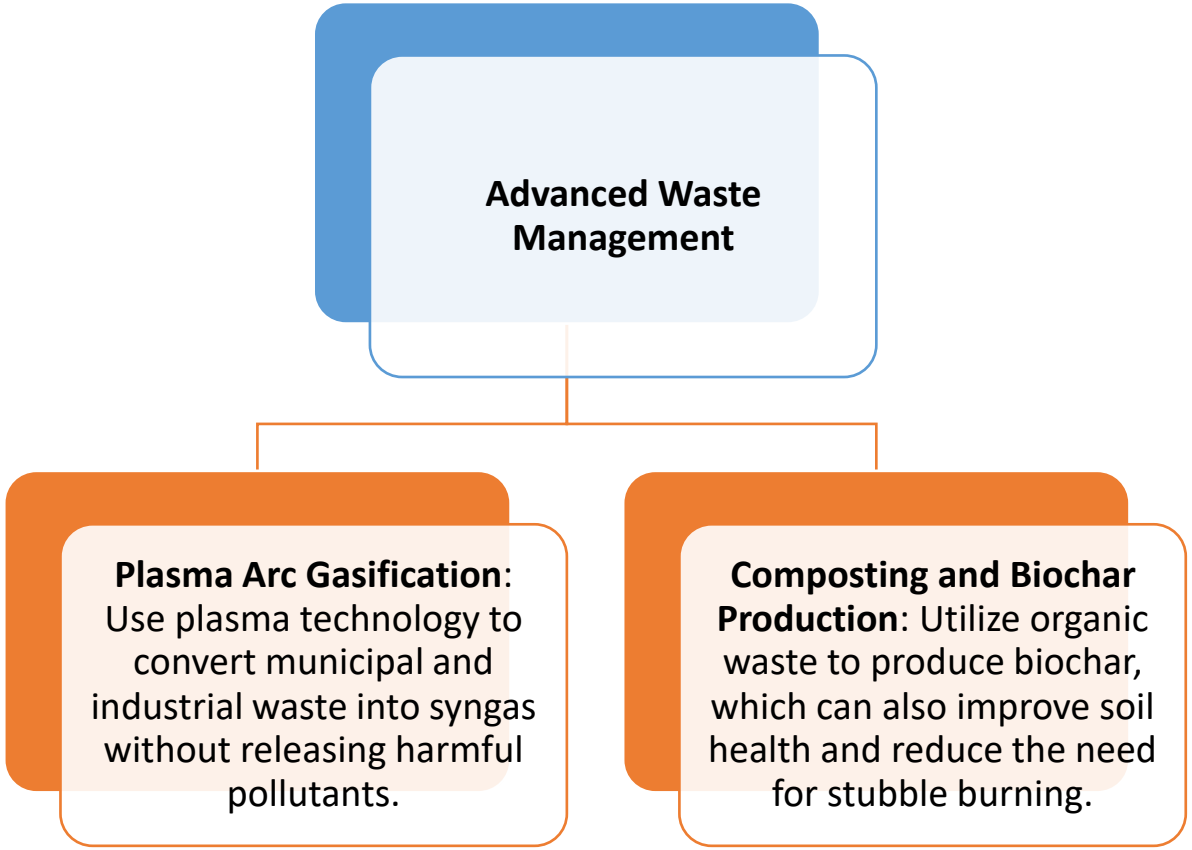
Assignment

- What other measures (technical solutions) may be used to remedy or counter SMOG crisis?

Renewable Energy Integration

Solar and Wind Energy: Expand renewable energy infrastructure to reduce dependence on coal-fired power plants, a major source of emissions.

Distributed Energy Systems: Promote rooftop solar and microgrid technologies to decentralize energy production.


Advanced Waste Management
Plasma Arc Gasification: Use plasma technology to convert municipal and industrial waste into syngas without releasing harmful pollutants.
Composting and Biochar Production: Utilize organic waste to produce biochar, which can also improve soil health and reduce the need for stubble burning.

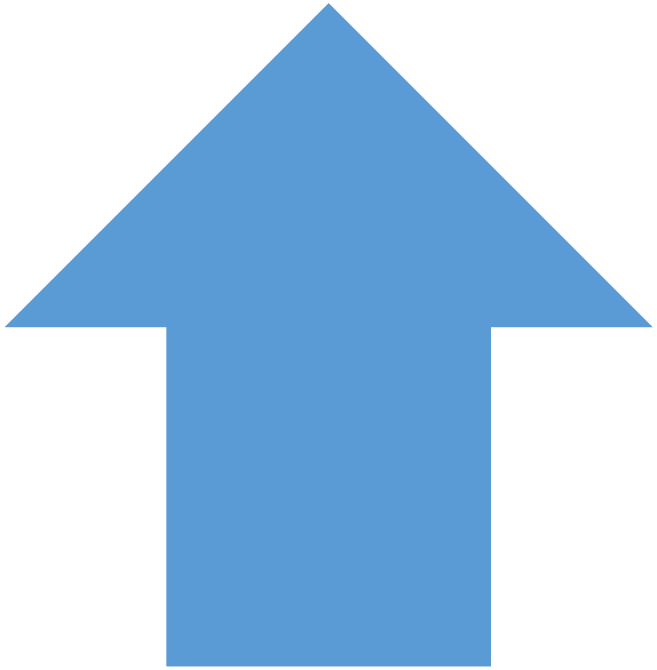
Monitoring and Data-Driven Solutions

- **Air Quality Sensors**: Deploy a network of low-cost, high-accuracy sensors to monitor real-time air quality at micro-levels.
- **Satellite Technology**: Use satellite imagery to identify pollution hotspots and track smog dispersion patterns.
- **AI and Machine Learning**: Leverage AI to predict pollution trends and optimize pollution control measures.

Carbon Capture and Storage (CCS)

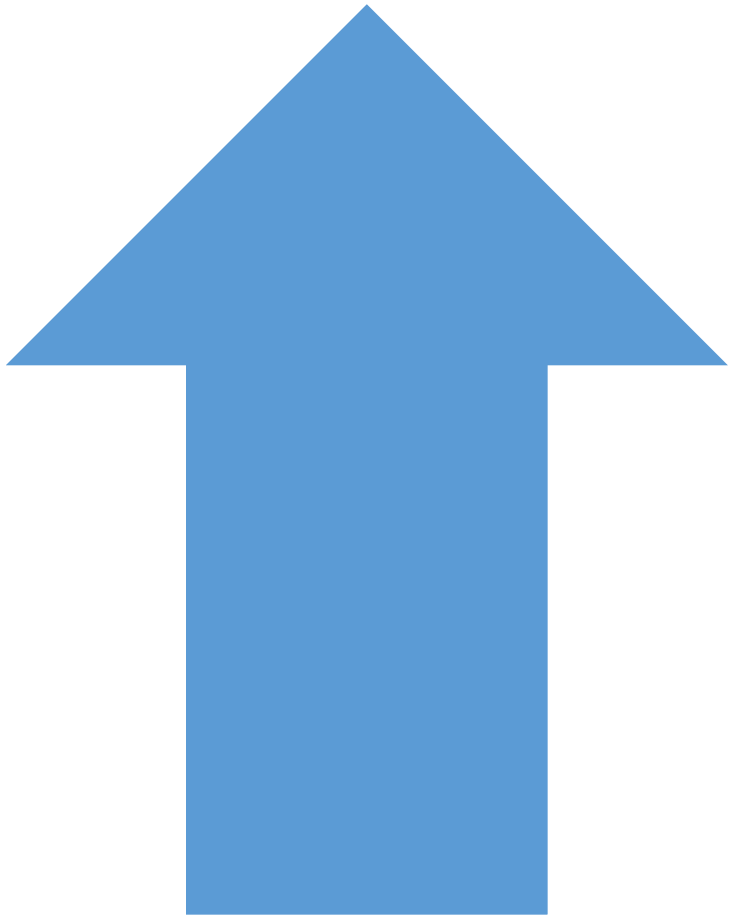
Point-Source Carbon Capture: Install CCS systems at industrial facilities to capture CO2 before it enters the atmosphere.

Bioenergy with CCS (BECCS): Integrate bioenergy production with carbon capture technologies for a net-negative emissions process.



Green Building Technologies

- **Green Roofs and Vertical Gardens**: Incorporate vegetation into building designs to absorb CO2 and particulate matter.
- **Energy-Efficient HVAC Systems**: Use air purification and ventilation systems in buildings to maintain cleaner indoor air.



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Atmospheric Technologies

Cloud Seeding: Deploy cloud-seeding techniques to induce rain, which can wash away airborne pollutants during severe smog episodes.

Geoengineering: Research and potentially implement geoengineering solutions like stratospheric aerosol injection to reduce heat and subsequent ozone formation.

Smart City Integration

- **IoT-Driven Pollution Control**: Integrate Internet of Things (IoT) devices into urban infrastructure to dynamically manage air quality.
- **Clean Zone Implementation**: Establish low-emission or zero-emission zones in cities using automated monitoring systems.

- **Smog-Eating Concrete**: Use photocatalytic concrete that reacts with sunlight to break down pollutants like NOx.
- **Paints and Coatings**: Apply photocatalytic coatings on buildings to reduce air pollution passively.